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Generation of complex, dynamic temperature gradients in a disposable microchip

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Abstract

We present a temperature gradient (TG) generation method using acoustothermal heating of polydimethylsiloxane (PDMS) by surface acoustic wave (SAW) microfluidic system. Independent and precise control of each SAW from a slanted interdigital transducer (IDT) enables a one-dimensional (1D) spatiotemporal control of temperature in a PDMS microchip. Various TGs were created in gas and liquid. The system creates switchable, dynamic and complex TGs in a disposable microchip.

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1. Introduction

TGs in fluids play a crucial role in many biochemical applications (Mao *et al.*, 2002; Yang *et al.*, 2014; Ross and Locascio, 2002). The most popular method used to generate TGs has been to put a heat source on one side and a heat sink on the other, making a linear temperature profile across (Mao *et al.*, 2002; Yang *et al.*, 2014). A drawback is that the large heating area prevents the integration of multiple functionalities on a single substrate. Furthermore, the system is nonswitchable and static. Here we report a generation of complex, dynamic TG based on an acoustothermal heating of disposable PDMS microchip. The heating mechanism utilizes vibration damping in PDMS induced by sound waves

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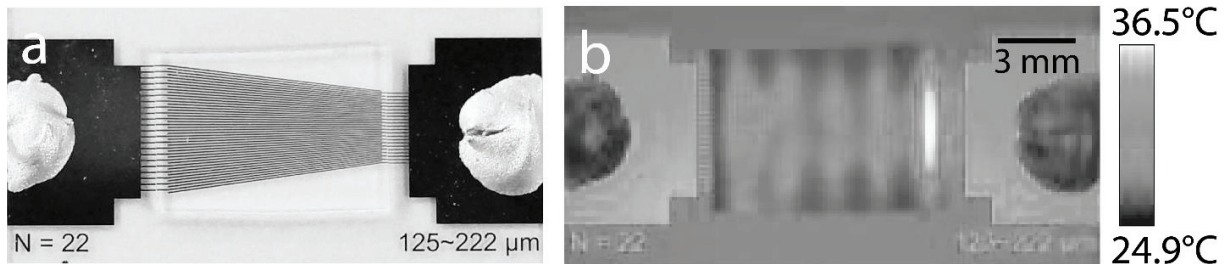


Figure 1 Photographic images of TG generation system: **a**, a thin PDMS slab on a slanted IDT. **b**, infrared image of the heated PDMS slab.

that are generated and minutely controlled using a conventional SAW microfluidic system (Ha *et al.*, 2015). The key advantages are rapid, uniform heating from its volumetric nature and a spatiotemporal control of temperature on a chip. Independent actuation of portions of a slanted IDT enables a one-dimensional (1D) local control of PDMS temperature. Thus, by placing a PDMS microstructure on top of a slanted IDT, we can make various 1D TGs either in the air right above a thin PDMS layer or in the liquid in a microchannel.

2. Results and discussion

The TG generation system for gas comprises a 700 μm-thick PDMS slab mounted on a slanted IDT (Fig. 1a). An AC signal time-shared (0.001 sec each) by five different frequencies (18, 20.5, 22, 25.5 and 30 MHz) was applied to heat five different positions of the PDMS slab simultaneously (Fig. 1b). This approach enables an independent control of temperature over a line across the IDT in a spatiotemporal manner. The same system was used to successfully establish four different types of TGs in the air right above the PDMS slab (Fig. 2): linear from 45°C to 86°C (Fig. 2a), Gaussian from 44°C to 87°C (Fig. 2b), two-peaks from 72°C to 85°C (Fig. 2c), and linear (reverse direction) from 90°C to 58°C (Fig. 2d). The AC signals time-shared by multiple frequencies with different amplitudes were applied to form such TGs.

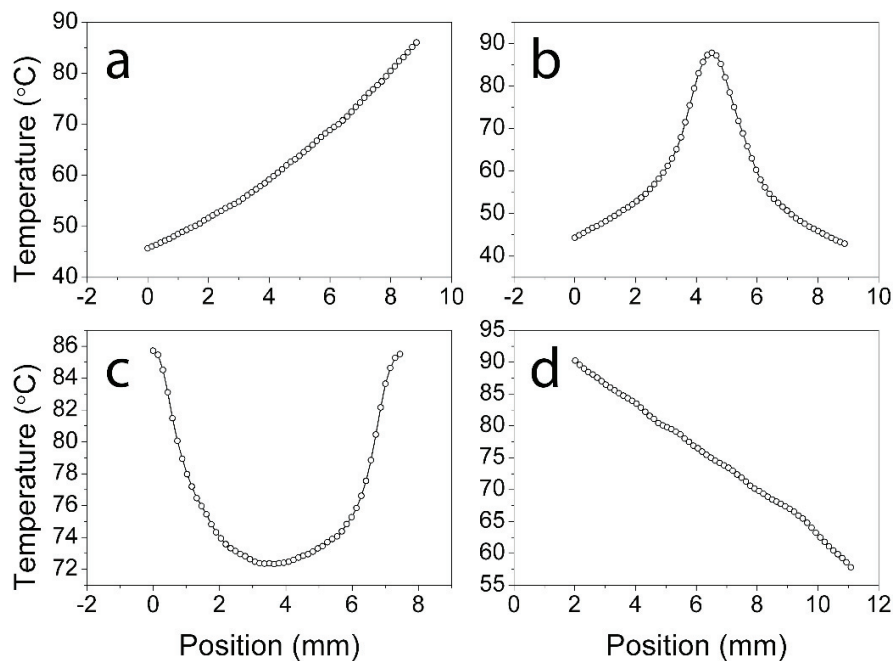


Figure 2 Graphs of temperature profiles for various temperature gradients: **a**, linear. **b**, Gaussian. **c**, two-peaks. **d**, linear (reverse direction).

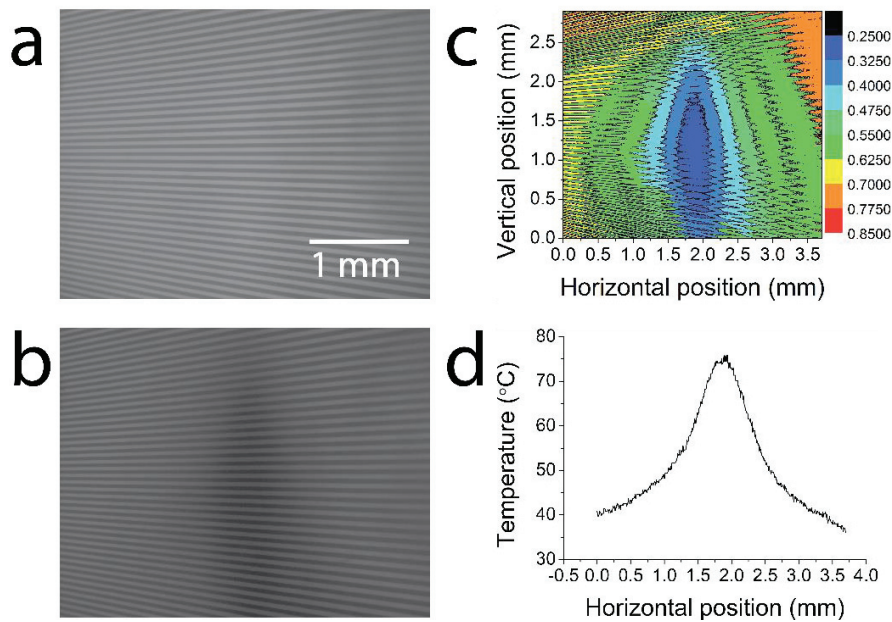


Figure 3 **a**, micrograph of a fluorescent image of the microchannel filled with rhodamine B solution without a temperature gradient (23 °C throughout). **b**, micrograph with a temperature gradient. **c**, contour graph for fluorescent intensity ratio (b over a). **d**, calculated temperature profile over the horizontal center line.

The TG generation system for liquid comprises a microchannel-molded PDMS microchip mounted on a slanted IDT. The volumetric heating of the PDMS effectively heats the liquid contained in a microchannel by conduction through the four walls (Ha *et al.*, 2015). Rhodamine B solution was used to measure the temperature profile in the microchannel. The fluorescence of rhodamine B solution reacts to the change of temperature (Ross *et al.*, 2001). Normalized fluorescence intensity ratio (Fig. 3c) was obtained from dividing the image taken at the heated state (Fig. 3b) by that at the reference temperature (Fig. 3a). Temperature profile was calculated by the calibration curve based on the obtained ratio values (Fig. 3d) (Ross *et al.*, 2001). As the horizontal center area was heated by the slanted IDT, the temperature in the middle was increased up to about 75 °C. As a result, a Gaussian temperature gradient was formed in the rhodamine B solution in the microchannel. As we can control the temperature in the microchannel in a spatiotemporal way, we can generate various TGs as we did for gas. The system could be very useful for combinatorial and parallel data acquisition of biochemical experiments as a function of temperature. As an application, one-shot high-resolution melting curve analysis could be performed to efficiently detect single nucleotide polymorphisms.

3. Methods

TG generation in gas

The TG generation system for gas comprises a thin (~700 μm) PDMS slab mounted on an IDT-patterned lithium niobate (LN) substrate. Metal layers of Au/Cr (1000 Å/300 Å) were deposited onto the substrate via e-beam evaporation lift-off process to pattern a slanted IDT whose finger gap periods ranging from 125–222 μm and electrodes. A 500 μm thick 128° y-x cut x-propagating LN was used for the substrate (MTI Korea, Seoul, Korea). The PDMS slab was prepared using 10:1 ratio of PDMS base (Sylgard 184A, Dow Corning, MI, USA) and curing agent (Sylgard 184B, Dow Corning, MI, USA). The system was actuated using high-frequency (~MHz) AC signals which was generated by a signal generator (N5181A, Agilent Technologies, CA, USA) and amplified by a power amplifier (LZY-22+, Mini-Circuits, NY, USA). The temperature distribution on the surface of the PDMS was measured by an infrared camera (A325sc, FLIR Systems, OR, USA).

TG generation in liquid

The TG generation system for liquid comprises a PDMS microchip mounted on an IDT-patterned LN substrate. The IDT was patterned the same way as used in the TG system for gas except that the finger gap periods were from 100–200 μm . The microchip is composed of a microchannel-molded PDMS slab and a thin ($\sim 200\ \mu\text{m}$) PDMS layer bonded at its bottom to close up the channel. The microchannels were fabricated through soft lithography technique using SU-8 replica molding protocols. The fluorescence intensity of rhodamine was measured by a CCD camera attached on top of a microscope.

4. Conclusions

A TG generation for gas and liquid has been presented. The suggested method can generate complex, dynamic TG on or in a disposable microchip. The approach adopts a conventional surface acoustic wave microfluidic system, taking advantage of simplicity and portability of the system. Using slanted IDTs, we were able to have a spatiotemporal control of temperature on or in the microchip. Various 1D TGs were successfully created in gas and liquid. The system is switchable, dynamic, transparent, inexpensive, easy-to-fabricate, disposable and portable.

Acknowledgements

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